# Montana's Involvement in the High Plains Experiment



## Biennial Report 1977-1978



MONTANA DEPARTMENT OF NATURAL RESOURCES & CONSERVATION DNRC

WATER RESOURCES DIVISION

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# CHAPTER I

# INTRODUCTION

Rich Moy

The High Plains Cooperative Program known as "HIPLEX" is a research project designed to develop an effective, scientifically and socially acceptable weather modification technology for increasing spring and summer rains over the semi-arid High Plains.

During the 1977 and 1978 biennium, the first of three experimental phases was completed and preparations began for designing and implementing the second phase which will begin in 1979.

Montana's responsibilities through the Montana Department of Natural Resources and Conservation in HIPLEX may be summarized into four categories:

1. Assisting in the design of HIPLEX research;
2. Determining and evaluating the social, agricultural, legal, environmental, and economic impacts and benefits of spring and early summer rainfall augmentation programs in Montana and the northern High Plains;
3. Providing an independent analysis and evaluation of HIPLEX meteorological data with emphasis on state and local interests; and
4. Disseminating information generated from HIPLEX to Montanans, as well as seeking guidance from Montanans toward HIPLEX research.

In fulfilling its responsibilities during the 1977-78 biennium, the Montana HIPLEX staff and its contractors have summarized their accomplishments and findings in the following chapters: Meteorological Activities in Chapter II, Agro-ecological Studies in Chapter III, and General Activities in Chapter IV.

Chapter II, Meteorological Activities, is divided into four sections: data collection, data reduction, data management, and data analysis and meteorological planning.

The data collection section discusses the modifications made in the operation of the raingage network during the 1977 field season, and the objectives of the "weather watch." Because raingage data were not required during 1978, the raingage network was removed in late 1977.

The data reduction section reviews the procedures for reducing precipitation charts and for specifying radar echoes which were used for establishing the convective complex climatology. This section also discusses a study which was designed to identify criteria which would be used to suspend cloud seeding in eastern Montana.

The third section, data management, covers the editing of the 1976 Montana HIPLEX precipitation data base and summarizes two techniques for reducing raingage data (the digitization and manual methods). The last portion of this section reviews the memorandum by J. Boatman in which he analyzes climatological data from weather stations in eastern Montana for the period 1949-1973 in an attempt to establish a rainfall climatology.

The last section of this chapter, data analysis and meteorological planning, summarizes ten analyses or planning tasks. They cover a wide variety of topics including a climatology of eastern Montana, data analysis from Phase I of the research program needed to assist in the design of Phase II, analyses to establish a need for, and the density of an expanded raingage network for Phase II. and feasibility studies for a network of weather stations (mesoscale network) in eastern Montana.

Chapter III, Agro-ecological Studies, summarizes three studies related to the effect of additional rainfall on the native range ecosystems of eastern Montana.

The first study summarizes the finding from the first year and a half of a five to six year irrigation study. This study is designed to determine and quantify the short- and mid-term affects of a precipitation augmentation program on the quality and quantity of forage production, relationships between plant growth and plant and soil water, invasions of either desirable range grasses or weedy species, changes in species composition, and many other important ecosystem consequences.

The second study is concerned with the short- and mid-term effects of a precipitation augmentation program on carbon cycling and community dynamics, specifically on insect population and cattle. This study is of significance because grasshoppers, aphids, and a few other insects are sensitive to weather patterns and can compete effectively with cattle and sheep for forage on the High Plains.

In the third study, 26 years of rainfall and temperature data at Mildred, Montana, were correlated with basal area measurements of native rangeland vegetation at five permanent sites which were measured in 1936, 1938, 1963, and 1975. This study showed significantly more April and June rainfall during the 1963-1975 period than during the 1949-1962 period. The basal area and the expected forage yield almost doubled during the 13 year period of 1963-1975.

Chapter IV, General Activities, covers such activities as the information programs given by the state HIPLEX staff, activities of the clerical staff, and a listing of the different computer software packages developed by the Montana HIPLEX staff.

# CHAPTER II

## METEOROLOGICAL ACCOMPLISHMENTS

### A. Data Collection

1) Raingage network - Larry Holman

The raingage network operated during the 1977 field season was similar to the one operated in 1976 except for the following modifications (refer to the Montana Annual Report (Moy, *et al.*, 1976) for specifications and a description of the 1976 network).

a) At 19 of the 109 sites, a second Belfort raingage with a weekly rotating chart drive was co-located with a gage having daily rotating chart drive. The purpose of the co-location was to resolve time and measurement differences between the two types of chart drives. A preliminary review of the data suggests that the time resolution errors and the frequency of clock stoppages were both greater for the gages with weekly chart drives (memorandum by L. Holman and J. McInerney, 10 January 1978).

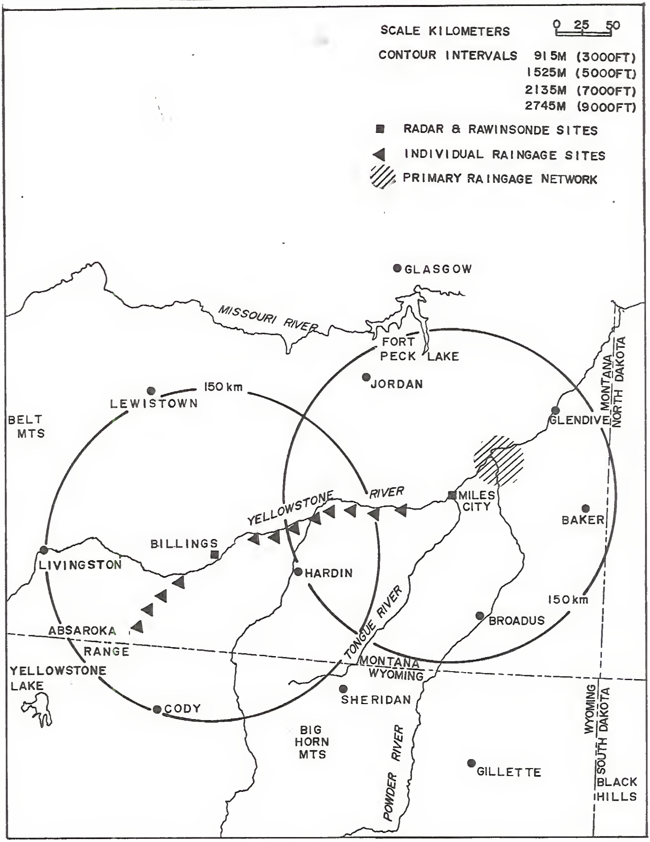
b) No hail pads were used during the 1977 field season because the weekly servicing schedule was too infrequent to distinguish individual hail storms and their relative intensities. A review of the 1977 hail insurance records for eastern Montana suggests that it is not uncommon for hail storms to be grouped with two to five day periods and then be absent for long periods.

c) Instead of using cluster raingage sites as was done in 1976, a line of twelve gages was installed extending from west of Miles City through the common coverage of both the Miles City and UND radars into the sole coverage of the UND radar at Billings (Figure 1). The raingages were spaced approximately every 18-20 km from Rosebud, Montana, to Red Lodge, Montana, except within the "black hole" (20 km radius of the UND radar at Billings). The purpose of the line of gages was to compare the radar-rainfall relationships of the two radars and to investigate the rainfall gradient along the Yellowstone River to the Absaroka Mountains.

d) Since the testing of the telemetry gages was concluded in 1976, none of these were co-located with Belfort gages in 1977.

e) Fewer maintenance problems occurred during the 1977 field season than in 1976 because of the following modifications. All gages were assembled with identical parts when possible and tested in the laboratory for one to four weeks prior to the field season. During the testing period, the performance of each clock and gage unit was checked and documented carefully to mitigate possible problems. When each gage was operating satisfactorily, its components remained as a unit. For transporting to the field, each chart drive was removed from the raingage and both the gage and chart drive were packed and handled carefully. At each site, each raingage was re-assembled and re-calibrated. Most gages were tested for one week in the field before actual data collection began. During the weekly service, each gage was serviced following the new comprehensive Belfort gage service check list as shown in the memorandum by L. Holman and J. McInerney (10 January 1978). If a problem

Figure 1. Line of twelve Belfort raingages (▲) extending along the Yellowstone River from Miles City through Billings and then to Red Lodge, MT. The radar coverage from the Billings and Miles City radars are indicated by the two large circles.



existed with a gage unit, repairs were generally completed within 24 hours. In addition, a more competent service crew was hired and given extensive training prior to the field season. Because of the above reasons, the total satisfactory operating time of gages increased from 89.7 percent in 1976 to 98.3 percent in 1977.

After the conclusion of the field season, all gages were removed and the site enclosures dismanteled by 15 October 1977.

A memorandum by L. Holman (23 February 1978) was sent to Denver listing proper procedures and potential problem areas associated with operating a successful raingage network.

2) <u>Weather watch</u> - Tom Engel

During the 1978 field season, Montana HIPLEX meteorologists shared in the daily responsibility of observing and keeping a log of local cloud formations. The primary purpose of the weather watch was to detect the onset of convection so that an aircraft mission could be launched while the clouds were most suitable for study. Information derived from the weather watch was also intended to be used for later analysis and reference, such as typing each day's weather conditions. The weather watch generally began at 1000 MDT and terminated at 2000 MDT.

Impressions of the utility of the weather watch after the 1978 field season were favorable.

B. Data Reduction

1) <u>Precipitation charts</u> - Jim McInerney

A total of 7,495 precipitation charts from the Montana, Kansas, Texas, and Sierra gage networks were processed in 1977 and 1978.

The following procedure was used to reduce charts into a format compatible for storage in the Bureau of Reclamation's Cyber computer system in Denver:

a) Each chart was numbered in the sequence that it was placed on the gage; for example, chart No. 1 was the first of the season, No. 2 was the second chart of the season, etc.

b) Subsequently, each chart was manually inspected to locate storm occurrences. A storm occurrence is defined as .01 inches minimum rainfall total within a 15 min period separated by at least three hours between storm events.

c) Storms were extracted from the charts with a Tektronix 4051/4956 digitizing system.

d) These data were then transferred to the Cyber compuer system and merged into a single, indirect access file considered to be the unedited data base.

e) An editing program was run on this data base to produce a listing of the storms along with a listing of the gages that recorded precipitation and total rainfall for each storm occurrence.

f) From the listings, the amount of precipitation received at each respective gage during each storm occurrence was plotted on a map of the gage network.

g) If more than five adjacent gages showed precipitation during a particular storm period, the precipitation charts from adjacent gages not showing precipitation were rechecked visually. If precipitation was found in an adjacent gage, the gages adjacent to this gage were rechecked. This procedure was followed until all gages with precipitation were bounded by gages verified as having had no precipitation.

If less than five gages showed precipitation, or if gages not adjacent to each other had precipitation, their respective charts were rechecked and the data were corrected, when necessary. During this editing process a revised hand-plotted map of gages was constructed showing precipitation for each event, so that at the end of the editing process, subjective plots of storm totals existed for each storm.

h) The newly corrected charts were then re-digitized and the corrections made to the data base. When all errors were corrected, a second computer listing of the storms was compared to the hand-edited maps of the network. When both maps and storm listings agreed, the editing process was considered complete.

i) Finally, the Bureau of Reclamation in Denver was notified of the corrections and the data base changes were made permanent and a copy archived.

More detailed information on the editing procedures and computer software is contained in a memorandum sent by J. McInerney to J. Klazura dated 14 February 1978.

2) Radar echo boxing for the convective complex climatology - Tom Engel

An integral part of establishing a convective complex climatology over the HIPLEX study area was the boxing and digitization of radar echo coordinates on the University of North Dakota generated PPI displays of maximum reflectivity and echo top heights. This information was used in various climatological and other analyses (see Data Analysis and Meteorlogical Planning section).

Criteria based solely on radar data were first used to isolate and classify the echoes suitably as convective complexes from all other echoes appearing on the PPI display. These criteria, as documented by E. Holroyd of the Bureau of Reclamation (memorandum of 19 September 1978), were that a particular echo must exceed at some point in its lifetime a reflectivity of 30 dBZ and an echo top height of 8.5 km. All echoes determined through the use of satellite photos to be mountain-generated were removed from this suitable echo subset to generate the convective complex climatology.

Each echo determined to be a convective complex by the above procedure underwent a boxing and digitizing process designed to generate data on the Bureau of Reclamation's Cyber computer system suitable for processing with existing software so that radar-estimated rainfall "footprints" could be computed. A breif description of the boxing digitization process follows.

On each volume scan of the PPI display, lines of constant radius, R, or azimuths, Θ, (theta) were hand drawn around each echo determined to be a convective complex. These PPI displays were then placed on the on-site Tektronix 4051/4956 digitizing system and the R and Θ coordinates of those lines were selected, using software designed for that purpose (see "Computer Software Design" section). These data were temporarily stored locally on magnetic tape and then transferred to the Cyber computer system to generate the data files necessary for later processing.

Most of the boxing and digitizing work was performed by the Montana HIPLEX staff. This data reduction procedure is still under way on 1976 and 1978 radar data with 1977 being completed. This procedure is intended to continue in future years.

3) Hail climatology - Larry Holman

The incidence of hail in eastern Montana was documented from hail records collected by the Montana Department of Agriculture's Board of Hail Insurance. These records were analyzed for hail occurrence during the May-July field seasons of 1976, 1977, and 1978 within the Miles City radar coverage. Information obtained on the location, time and severity of hail damage will be cross referenced with other meteorological data in an attempt to identify those meteorological situations where potentially severe weather occurred. It is hoped that some parameters from the radar reflectivity records, or a combination of other radar parameters such as storm height, storm thickness, etc., may be correlated with or related to hail. In this way, such parameters, when identified in real time, may serve as criteria to suspend or postpone mission activity. These analyses are now proceeding.

C. Data Management

1) Precipitation network gage locations - Jim McInerney

As a part of the quality control on HIPLEX precipitation data, the documented locations of raingage sites in the 1975 and 1976-77 precipitation networks were rechecked for accuracy in October 1977.

Using the documented coordinates, the site locations northeast of Miles City were re-calculated for a rectangular coordinate system. The origin of this system, 46° 28' 21" N by 105° 35' 10" W, was positioned one minute latitude south of the southernmost point of the network and one minute longitude west of the westernmost point of the network. A great circle navigation routine was used to determine azimuth and range from the origin. Site locations were then plotted on graph paper and visually

inspected by personnel familiar with the networks. These plotted locations revealed a few obvious errors in the documented coordinates of the sites.

Gage locations which appeared to be in error were located on U.S. Geological Survey 7.5 minute maps through recognition of land features. Their latitudes and longitudes were recalculated by hand and all corrections were documented. It is felt that these corrective procedures now insure the accuracy of documented site locations.

2) Comparison of digitized vs. manual data processing - Larry Holman

a) Nineteen Belfort raingage charts from the period of 25 April 1977 to 20 May 1977 were reduced by two methods. The first method required visually determining the magnitude and timing of an ink trace on a chart and assigning the appropriate rainfall values for the respective time interval. This method, referred to as the "manual" technique, usually required two people working as a unit with the first person calling values to the second person who recorded the information on a computer coding form. Approximately 25-30 charts per day could be read by this method.

The second technique involved using a Tektronix 4956 digitizing tablet interfaced to a Tektronix 4051 minicomputer. This "digitizing" method required setting an electronic probe on the critical junctures, slopes and points to resolve precipitation totals for various time periods. One person can reduce 60-80 charts per day with the digitizer.

These two techniques were compared (memorandum J. Boatman, 26 July 1977) and the results indicated that errors could result from both methods; however, discrepancies between the two techniques were usually minor.

Subsequent to the above study and as discussed earlier in this section, the quality control procedures were intensified for the digitizer to assure a relatively error-free data base. A final error analysis, as prompted by this study, is a routine aspect of digitized data reduction at this time.

a) Rainfall data from eight days in 1976 were reduced by two schemes. The Illinois State Water Survey reduced the data by digitization and the DNRC reduced the data manually. The data reduced by the two schemes correlated well and were thought to be compatible. The procedures are outlined in a memorandum sent by J. Boatman to the HIPLEX Director (10 March 1977).

It should be noted that both of these studies were conducted only on small portions of the total available precipitation data and, since they were special intercomparison studies, the reduction procedures used in obtaining the data for comparison were of higher quality than that of normal reduction procedures. Analyses utilizing the complete data base of 1976, which was manually reduced, and of 1977, which was reduced using the digitizer-minicomputer, have shown that digitized data is of considerably higher quality than manually reduced data. This is especially true of precipitation occurrences since individual clocks may run fast or slow. Additionally, the possibility of human error is significantly reduced in

incorporating a computerized data reduction scheme. Therefore, it should be noted that contrary to many previously (and currently) held beliefs, digitization of precipitation records provides a data base far superior to that produced manually.

3) 1976 Montana HIPLEX precipitation data base - Tom Engel

Isolation of precipitation events over the Montana HIPLEX raingage network from convective complexes (outlined in the "Data Analysis and Meteorological Planning" section of this report) was one of the first tests of the accuracy of the precipitation data bases. It was found that the 1976 data base, which was manually reduced, was in need of considerable editing. An editing procedure, designed to locate and correct non-existent data and rainfall amount errors, was undertaken. After this editing, it was further found that timing errors also existed in the original data base. Consequently, additional editing to correct the timing errors was performed. This new data base is presently stored on the Bureau of Reclamation's Cyber computer system in Denver. Even with this editing, though, the quality of the 1976 Montana precipitation data base does not approach that of the 1977 data base (which was generated through procedures outlined in the "Data Reduction" section of this report).

4) Rainfall climatology - Larry Holman

A rainfall climatology was prepared from climatological weather stations in eastern Montana for the period 1949-1973 (memorandum by J. Boatman, 4 June 1977). From this rainfall climatology, several precipitation anomalies were noted that may influence the location and timing of an experimental rain augmentation program. Many of the features shown on the maps from the memorandum parallel many of the preliminary results using 1976 and 1977 radar data.

For eastern Montana, surface precipitation gradients exhibit variation with month and storm type. Most noticeably, the strongest surface gradients were associated with summer convective activity.

Precipitation amounts do not seem to be affected by eastern Montana topography.

From the analysis, it was suggested that if an experimental area was centered at Billings, as proposed at one time, a region of relatively heavy precipitation located approximately 60 km west-northwest of the city would be a potential area for a raingage network.

D. Data Analysis and Meteorological Planning

1) Summer rainstorm types and associated rainfall characteristics - Larry Holman

To better understand the characteristics of natural storms passing

over the Miles City HIPLEX Study area during May through July 1976, storm occurrences were first classified into five types with the aid of satellite imagery, radar, time-lapse photography, the HIPLEX raingage network, and the National Weather Service observations for this period (J. Boatman, *et al.*, 1977). Each storm type was analyzed for the amount, duration and frequency of rainfall produced, the timing of the rainfall event, the area coverage of the storm and its potential for increasing rainfall by seeding using different assumed models.

The results suggested that mountain-generated systems and cold fronts produce the most rainfall and that upper level troughs and mountain-generated systems had the highest number of hours of rainfall. It was also noted that a large portion of the mountain-generated storms may not be likely candidates for aircraft studies since they pass over Miles City area after dark.

2) <u>Convective complex precipitation analyses for 1976 and 1977</u> - Tom Engel

Shortly after the HIPLEX planning conference at Dillon, Colorado, in December of 1977, work was begun on determining a convective complex rainfall climatology. This rainfall climatology was based on the precipitation data collected during the 1976 and 1977 field seasons and was intended to provide a "best estimate" of the character of thunderstorm precipitation in eastern Montana so that work could then proceed on obtaining an optimum density for the then proposed 250 raingage network. Isolation of convective complex precipitation was carried out through objective analysis of then existing data. These data included: field operations documentation (aircraft crew voice tapes, debriefing transcripts, field notes from A. Super and C. Hartzell), laser-fax satellite photos, Super 8 time-lapse film, photos of MLS PPI radar scope at ½ hour intervals and precipitation data (at the time, no digital radar products were available). In the two years of data, sixteen rain events were classified as being from convective complexes, none of which were completely contained within the 1690 $km^2$ raingage network. These data were used by several individuals and groups in analyzing storm characteristics and precipitation variance (both real and sampling). It was realized that such a small and truncated sample could in no way be expected to realistically represent the population of convective complexes occurring naturally over the Montana HIPLEX operations area. The limited sample of convective complexes obtained in this analysis led to the decision to estimate total rainfall from radar data.

3) <u>Convective complex climatology</u> - Tom Engel

The lack of sufficient precipitation data to establish a realiable sample of convective complex storm totals led to the need to use precipitation estimates derived from radar data to provide such a representative sample. Additionally, a convective complex climatology was constructed.

Although Montana DNRC personnel did not play a major role in analysis of these data (other than obtaining some average sizes, durations and growth

rates), significant time was spent to first define complex classification criteria and later refine the reduction and analysis techniques. This climatology has been put to use in some planning studies. These studies are elaborated upon in subsequent sections of this report.

4) Application of rain cell approach to Miles City HIPLEX raingage data - Jim Heimbach

The rain cell method of Schickedanz (1972) was applied to eight days of storm activity sampled by the raingage network during 1976. Originally, the intent was to summarize one entire summer of rain cells; however, too much uncertainty developed over the 1976 15 min accumulations. Basically, a "rain cell" is a recognizable entity of surface measured precipitation within the overall isohyetal pattern. There were two questions addressed in this analysis (Heimbach and Gilkey memo to Super and Moy, 26 July 1977). (1) How do rain cells of 5-min sampling times compare with those of 15 min? (2) What are the characteristics of these rain cells?

From the analysis of rain cells it was shown that there was some definition lost by using 15-min totals in place of 5-min totals. Several extra rain cells were picked up on the 15-min analysis because of the time constraint used, but several were lost because of time smoothing.

The 15-min rain cells derived from eight days of data illustrate some characteristics of rainfall patterns in the Miles City area. (1) The rain cell approach may be useful in the analysis of seeding effects if some of the subjectivity of their definitions can be removed. (2) There are a reasonable number of rain cells per storm identified by the raingage network (mean= 10), significantly increasing the number of sampling entities if used instead of the whole storm. (3) Their occurrence is reasonable in terms of operational periods of the day and they are large enough to be recognized and sampled while for the most part not extreme in size. (4) Most of the cells are weak and their life is short, making rate or lifetime enhancement easier to detect. (5) Unfortunately, the standard deviations of the statistics described above are of the same magnitude as their respective arithmetic means, implying a large number of samples would be required to achieve a respectable level of confidence.

5) Towering cumulus climatology and cloud physics measurements - Tom Engel

In preparation for the next phase of the experiment, it was decided that existing data could prove useful in providing stratification or selection criteria for the experimental units; that is, the towering cumulus (TCU). Additionally, such data could also serve as predictor and/or response variables in the next phase. In response to these needs, analysis has begun on aircraft data obtained during the 1977 field season. Subjective determination of the passes through towering cumulus clouds was made using transcripts of air-crew voice tapes, debriefing transcripts, photographs (when available), and the aircraft data itself. Tabulation and plotting of measured parameters (such as temperature, liquid water content, ice crystal concentration, vertical

velocity and others) was begun in an attempt to gain insight into which parameters could serve as predictor variables. This study and the computer software designed for it was turned over to on-site federal personnel when problems more appropriate to Montana DNRC interests and abilities arose.

6) Mesonet - Tom Engel

The subject of including a surface mesonetwork in the Montana HIPLEX was raised at the Dillon, Colorado, conference in December, 1977. A mesonetwork is a network of stations separated by distances comparable to the size of a thunderstorm which monitor meteorological parameters such as pressure, temperature, moisture content of the air and wind velocity, and relatively small scale fluctuations in those parameters. At the Dillon conference little consideration was given to the idea, since plans for a raingage network were still being developed. In recent months, though, it has become increasingly obvious that the data currently being taken are not sufficient for providing definitive results on modification operations within a reasonable amount of time (cf. J. Heimbach's summary of raingage network density studies in this report). Thus, interest has arisen in utilizing a mesonet in helping to establish better stratification criteria or predictor variables on the experimental unit; i.e., a convective complex. Since DNRC personnel are very much interested in the collection, reduction, and analysis of mesonet data and especially since mesonet plans are still in the formative stages, considerable time has been spent in determining a scientifically justified design plan for the mesonet.

A literature review was performed and is presently continuing in order to familiarize DNRC personnel with existing mesonets and various aspects of their design. Additionally, analyses were performed and are continuing on determining the spatial and temporal scales of storms considered to be of the character most suitable for study. Further, absolute instrument accuracies and resolutions necessary for obtaining reliable information on meteorological parameter fields expected to accompany thunderstorms have been and are being investigated.

As a mesonetwork becomes a reality, DNRC personnel will play a major role in the design, deployment, and maintenance of the mesonet, as well as data management and development of software for real time and post-analysis purposes. There are, then, several major areas of work which remain to be completed. These include: investigation of the effects of the accuracies and resolutions of the various instruments on derived fields, justification of spatial and temporal sampling intervals, development of objective analyses schemes and data display routines for real-time computer processing, and development and testing of schemes which could lead to estimates of the "seedability" of storms (i.e. testing of possible mesonet derived predictor variables).

7) Definition of "Worst Case" convective complex - Jim Heimbach

Twelve convective complexes (cc's) sampled by the Miles City raingage network during 1976 and 1977 HIPLEX field seasons were analyzed to determine which would be considered the "worst case", such as what type of cc would make detection of a treatment effect most difficult. The twelve cc's were defined by examination of radar and raingage data (see memos by E. Holroyd, March 1978 and T. Engel, March 1978).

As presented in a memo by J. Heimbach (27 April 1978) the approach for defining the worst case is discussed below. Pseudo-convective complexes were computer generated over every possible position without redundancy on a hypothetical evenly-spaced gage network. Area rainfall totals were determined from the hypothetical network. Monte Carlo techniques were used to detect seeding effects from the hypothetical network.

The following was concluded from the analyses:

(1) sampling variance is a function of gage spacing;
(2) sampling variance is a function of a total storm area;
(3) average estimated cc area does not vary with gage configuration;
(4) the worst case is the small cc because it is simply easier to miss altogether with an evenly spaced raingage network; and
(5) the between-storm sampling variance is greater than within-storm sampling variance. In fact, the comparative magnitude of the between storm variance may be large enough to make the worst case definition a moot point.

8) Display of archived radar data - RPLOT Program - Jim Heimbach

RPLOT is a Fortran IV package developed at MSU which produces printer-plotter depictions of radar data from archived dBZ files. Any map scale and any zone of coverage can be specified, including the entire area of radar coverage. Individual tilt angles or composite modes are available and time periods can be averaged. Complete descriptions of its use and the assumptions applied are in a technical report by J. Heimbach and K. Gilkey, (Montana State University, December 1978) being prepared concurrently with this report.

(a) Procedures and assumptions used in RPLOT

1. Data

Data input is handled by a slightly modified version of subroutine GETDBZ written at the Department of Aviation, University of North Dakota. The programming is tailored to process the dBZ files whose format is described by J. Odegard (1977). Normally these files are large enough that they can only be stored on direct access files necessitating the use of the "ATTACH" command.

2. Choice of dBZ's to be displayed

More than one bin* can be found within the map boundaries of a specific print character. The largest dBZ returned from these bins is displayed. This is also the case for the display of returns from multiple tilts; i.e., composite scans.

3. Input parameters

Map scale, fiducial point, size of map in characters, scans to be averaged, beginning and ending data times to be sought, azimuths, elevations and minimum dBZ to be plotted are input at the beginning of the run. Single or composite modes can be specified. In the former case, an individual plot is made for each tilt range.

4. Time averaging

To adjust for dBZ's not being linearly related to reflecting volume, an arithmetic average of R is found using the Z-R relationship of Smith et al., (1975)

$$Z = 155 R^{1.88}$$

This average is converted back to a dBZ prior to display using the same formula.

5. Time saving features

It is necessary to include features which reduced the run time needed for handling such large amounts of data. After buffering in a record, only several identification parameters are decoded. First, the date is checked. If the data is as specified, then the time is checked. This process is continued through the azimuth and tilt ranges. Only after all identification parameters are found to be within specifications will the software decode the remainder of the record.

(b) Applications

The most widely used radar printer-plotter product used in Miles City is from North Dakota's RADPROC processing. This is a printer-plotter composite display and is produced for all 5-min scans. The entire scope coverage is placed on one printed page along with tracking and other information. Periods needing scrutiny on a larger scale have had RPLOT applied. In some cases the scale has been so large that the individual bins were spaced more than one print character apart. Examples of RPLOT's are first-echo studies and aircraft positioning ("skin paints").

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*A bin is defined as a volume for which a representative returned intensity is recorded. This volume is bounded by the cone of the radar beam and the concentric spheres from the radar. The beam width is one degree and the normal range increment is 0.5 km. (dBZ is ten times the log of effective radar reflectivity factor ($mm^6 m^{-3}$).

9) Raingage intercomparison study - Jim McInerney

The rainfall catch from five different raingages were compared during the 1976 and 1977 field seasons to determine wind-induced differences or errors in the rainfall catch data. The types, numbers, and orifice heights of the raingages are shown in Figure 2. Wind speed was recorded near the raingages by an anemometer connected to a Rustrak strip chart recorder.

Preliminary analyses of the wind speed and rainfall totals for each storm period in 1976 suggested that wind induced errors were not measurable (memorandum by A. Super and L. Holman, 7 April 1977). Further analyses of both the 1976 and 1977 data revealed the following for the range of conditions sampled:

(a) No difference was detectable in the rainfall catch totals of Belfort raingages with and without a Nipher wind shield.

(b) The variance of the rainfall catch between wedge gages at the same height was as great as the variance between heights. However, theoretically, if there was a measurable wind induced error, the variance of catch between heights should be greater than the variance at the same height.

(c) The storm totals of the wedge gages and Belfort gages were similar and the forestry and canister gage storm totals were also similar, but the latter two gage types recorded consistently higher storm totals than the former two. Because of this discrepancy, each gage was recalibrated and all were found to be calibrated within their resolution limits.

The preliminary results seem to suggest that wind induced errors are unresolvable between the heights of the gages. If the study is continued, the following modifications should be implemented:

1. In addition to collecting the recorded catch data at each gage, the actual volume of water collected should be measured and converted to a precipitation total. This would be a second check to insure the accuracy of the data recorded;

2. Since it is questionable whether Belfort raingages accurately record rainfall at the surface height, a new experiment should be designed.

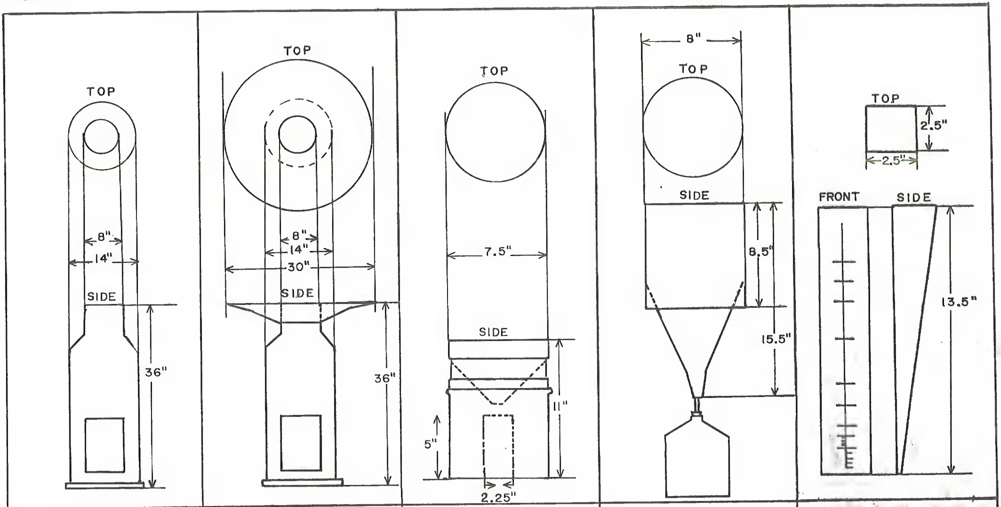
Four Belforts at ground level (pit gages) and four Belforts at the present height (43 inch orifice height) should be installed. Storm rainfall totals and wind speed data would be analyzed to establish the relationship between total rainfall at the ground and at the above ground height. By combining wind speed and rainfall total for each storm period, an estimate of true rainfall could be made.

10) A Monte-Carlo approach for estimating rain gage density requirement - Jim Heimbach

A simulation approach was used for estimating an optimal raingage density needed for sampling convective complexes during the next phase of

FIGURE 2. Types of rain gages compared to determine wind-induced differences in rainfall catch.

Figure 2.

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|---|---|---|---|---|
| TYPE: Belfort weighing rain gage (recording)<br>RESOLUTION: ± .01 in.<br>NUMBER USED: 1<br>ORIFICE HEIGHT: 43 in.<br><br>EXPLANATION: Storm times and amounts are recorded on a chart mounted on a rotating cylinder. | TYPE: Belfort weighing rain gage (recording) equipped with Nipher wind shield.<br>RESOLUTION: ± .01 in.<br>NUMBER USED: 1<br>ORIFICE HEIGHT: 43 in<br><br>EXPLANATION: Same gage as previous one except the Nipher wind shield was used to reduce the wind updraft at orifice of gage. | TYPE: Forestry dip-stick gage (non-recording)<br>RESOLUTION: ± .02 in.<br>NUMBER USED: 4<br>ORIFICE HEIGHT: 57 in. (2), 15 in. (2)<br><br>EXPLANATION: Rainfall amounts read and recorded after storms. | TYPE: Sunken canister gage (non-recording)<br>RESOLUTION: ± .05 in.<br>NUMBER USED: 2<br>ORIFICE HEIGHT: 15 in. (2)<br><br>EXPLANATION: Volume of precipitation measured after the storm and converted into precipitation amounts. | TYPE: Wedge gage<br>RESOLUTION: ± .01 in.<br>NUMBER USED: 4 (1976), 8 (1977)<br>ORIFICE HEIGHT: 15 in. (2,4); 43 in. (2,2); 57 in. (0,2)<br><br>EXPLANATION: Rainfall amounts read and recorded after a storm. |

the experiment. Three tradeoffs were considered:

1) sampling variance increases with increasing gage spacing;
2) adding gages requires additional resources; and,
3) the number of storms which can be sampled per season increases with the areal size of the network.

This approach used total rainfall accumulation "footprints" from 103 convective complexes as estimated from radar data. Simulated hexagonal gage networks of various spacings (densities) were placed over these footprints to estimate one rainfall total for each storm. For a given gage configuration, samples were randomly chosen, then randomly "seeded" to provide a data base for the Wilcoxon or Mann-Whitney (Noether, 1967; Mielke, 1967) tie-adjusted rank-sum test. Samples were added to the simulated data base until a desired $\alpha$ - probability level was reached. This process was repeated 100 times for each simulated network to give distributions of the number of storm samples needed to reach an $\alpha$ - probability level for a "seeding effect" (percentage increase) of $\delta$. The number of samples needed to reach specific $\beta$ - probability levels was found from the resulting distribution of numbers of cases needed. A complete description of the techniques and assumptions is given in a memo by Heimbach and Super (6 September 1978).

Preliminary results using all 103 convective complexes suggests a marked deterioration of treatment detection at a density between 350 to 650 $km^2$ per gage or a between-gage spacing 12 to 20 miles. The number of storms required to meet $\alpha$ and $\delta$ specifications is highly correlated to the number of times simulated samples had zero rainfall; i.e., when the radar footprint was missed by the "network".

It can be assumed that the maximum network size to detect a treatment in the complete size spectrum of storms will be the area of radar coverage (71,000 $km^2$). Then the optimal spacing for 250 gages is to spread them throughout the entire area resulting in 284 $km^2$ (109 $mi^2$) per gage. For $\alpha = 0.05$, and $\delta = 0.10$, and no stratification of data, 254 storms were needed to detect $\delta = 100\%$. An examination of the 1977 radar climatology tempered with operational constraints suggests this would require about eight field seasons.

There was a greater ability to detect a treatment in the larger (greater than $0.247 \times 10^6$ $m^3$ accumulation) half of the 103 convective complexes. The smaller half, however, was shown to be nearly as difficult as the entire 103 sample for treatment detection. For a treatment effect of $\delta = 25\%$, $\alpha = 0.05$ and $\beta = 0.10$, both size classes required a prohibitive number of experimental seasons.

The results suggest two possible alternatives to the problem of detecting modest increases that might be associated with a future seeding experiment:

1. allow $\beta$ or $\alpha$ or both to be larger, and/or

2. delay specifications of the raingage network until covariants can be found which reduce between storm variance.

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# CHAPTER III

# AGRO-ECOLOGICAL STUDIES

## INTRODUCTION TO STUDIES

The following section includes three studies. The first study is concerned with the short-term impacts of different rainfall patterns and increases on range forage production. The second study is concerned with the late mid-term effects of additional rainfall on range yield and composition. The last study is concerned with the effects of additional rainfall on primary consumers and decomposers.

A. Ecologic effects of rainshowers on eastern Montana rangeland

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Objectives

Our objectives are to compare the effects--both positive and negative--of several patterns of rainfall application. We are determining: 1) in which season supplemental rainfall might have the greatest benefits, 2) how much rainfall must be supplied to be beneficial to existing communities, 3) whether any of the simulated rainfall patterns will encourage in three to six years (mid-term effects) the invasion of either beneficial species or pest species such as weeds, pathogens, or insects, and 4) what are the effects of discontinuing a successful precipitation augmentation program.

Work Performed

A technical report of 1977 work (Moy et al.) is available and a technical report of 1978 accomplishments is being prepared. The following paragraphs provide a relatively non-technical summary of our observations and tentative conclusions.

To determine the best seasons for rainfall application, the responses (e.g. forage production) of rangeland plots receiving normal rainfall (natural) are being compared with rangeland plots in which soils were kept moist in the following seasons; throughout the spring (spring wet), throughout the spring and summer (constantly wet), and only in the fall (fall wet).

To determine the quantities of rainfall needed to provide a favorable response during the growing season, the responses (such as forage production) of rangeland plots receiving normal rainfall (natural) are being compared with other plots guaranteed 6mm (1/4 inch), 12mm (1/2 inch), or over 25mm (1 inch, wet) of irrigation weekly.

These experiments are being performed on sites representative of relatively dry grasslands (*Bouteloua gracilis*) and relatively moist grasslands (*Agropyron smithii*) of the High Plains. Both sites are located on the U.S. Livestock and Range Research Station, Miles City, Montana.

Sites were located and equipment installed in 1977. Data were gathered during the relatively dry growing season of 1977, and during the relatively wet growing season of 1978. A severe hailstorm in 1978 affected 5-10% of our data. Irrigation will be continued for at least four more years (1979-1981) to determine the mid-term responses of supplemental water, such as the establishment of more productive species, establishment of weeds and outbreaks of

pathogens or insects. After irrigation ceases, monitoring is planned to continue for at least two years (1983-1984) to quantify the impacts of discontinuing a successful precipitation augmentation program.

Other HIPLEX and related studies have: 1) examined the effects of single showers on growth of wheat, barley, and native grasses, 2) sought reasons why responses to some showers were less than expected--daylength effects, root distribution effects, etc., 3) summarized information on climatic regimes (temperature and precipitation) and annual cycles of soil water availability and 4) examined the effects of irrigation on foothill (*Festuca idahoensis*) grasslands.

Tentative conclusions

Large showers were required to affect soil water content at depths of 10 cm or greater. In the relatively dry year of 1977, soil water at a depth of 25 cm became limiting to plant growth as follows: (1) in unwatered plots about 7 June; (2) in the light shower plots guaranteed 6mm of water/week drying was not postponed, (3) in the heavy showers plots (25mm/week), or spring wet plots in which irrigation was discontinued on 25-29 June, drying was postponed until 1 August; (4) in the constant wet plots in which irrigation was provided throughout the summer, the soil was prevented from drying altogether. In the relatively wet year of 1978, soil water at a depth of 25 cm became limiting to plant growth as follows: (1) in unwatered plots-about 10 July, (2) in the plots guaranteed 6mm of water/week drying was postponed until 15 July at the *Agropyron* site and until 21 July - 15 August at the *Bouteloua* site, (3) in the plots guaranteed 12mm of water/week drying was postponed until 20 July at the *Agropyron* site and until 15 August at the *Bouteloua* site, (4) in the spring-wet plots, in which irrigation was discontinued on 16 June soils were kept moist until 25 July at the *Agropyron* site and until 15 August at the *Bouteloua* site, (5) in the plots saturated with water in the previous fall soils were kept moist until 1 August at the *Agropyron* site and until 15 August at the *Bouteloua* site, and (6) in the constant wet plots soils were prevented from drying altogether. Light showers which closely follow other rainstorms probably have more beneficial effects than isolated (in time) showers because the rainfall from those following storms has a better chance of penetrating the soil. Water entering unfilled soil profiles in the fall, winter, or early spring is probably more effective in preventing soil drought than water applied during the growing season because a smaller percentage of it is lost via evapo-transpiration during the colder non-growing seasons.

Plants become water stressed when soil water becomes limiting. For example, in 1977, high plant water stresses were found in the unwatered *Agropyron* plots about 15 June, in the light shower plots (6mm) about 15 June, but never in the spring wet and constantly wet plots. The fact that soils dried in the spring wet plots without causing high plant water stresses suggests that stomates must have been tightly closed about 10 August to prevent transpiration, thereby maintaining low water stresses so effectively. This must have also limited production by making carbon dioxide unavailable. Data from 1977 for the *Bouteloua* site are similar.

Reduced water stress leads to increases in both gross production and net production (Table 1). Total forage (combined vegetative and reproductive production) was increased about 10% above the control by guaranteeing plants 6mm/week of rainfall, was increased about 30% above of the control by guaranteeing plants 12mm/week of rainfall, and was increased about 200% above the control by guaranteeing plants over 25mm/week of rainfall. Reproductive effort, which comprises a very small proportion of total production, increased even more strikingly above that of the control plots with more available water: by 40-140% with 6mm/week, by 80-180% with 12mm/week and by 200-2500% with 25mm/week. These data may conservatively estimate the benefits of supplemental water by rain showers since sprinkler irrigated water evaporates from our small (14 x 14m) experimental plots at relatively faster rates (oasis effect) than one would expect after rain showers. Next summer we plan to determine the magnitude of this oasis effect.

A graph of the yield data presented against the water treatments in Table 1 suggests that water use efficiency of plants decreases greatly as showers diminish in size. This is because much of the water supplied by a small shower is evaporated from leaves or surface layers of the soil without measurably benefiting the plant.

The season in which showers fall significantly affects the water use efficiency of plants. (1) Soil water stored in the fall, winter and early spring is efficiently used. Most of the water is stored beyond the reach of evaporation making it available during the spring growing period. (2) Rangeland grasses may be able to use May-June rainfall in excess of 25mm/week efficiently; the constantly wet plots out perform spring wet plots which received the same 25mm/week irrigation treatments during the May-June period. One could argue alternatively that this difference in response may be due to underground (root) growth in wet plots during the previous August and September. (3) Measurements of plant growth and forage production show that the growth of both *Agropyron* and *Bouteloua* slow markedly after 1 August even if the plants have plenty of water. Lab studies which will be repeated in the field, suggest that growth ceases at this time because shortening days induce the plant to prepare for late summer-fall, and/or winter dormancy. If plants are unable to use water to produce forage in August, then cloud seeding in this season can be justified only if it is adding water to soil reserves for use in the following growing season; that is, if rainfall comes as large showers or as a series of small showers which allow for the water to penetrate deep into the soil profile.

The production responses discussed above will apply only as long as the composition of the range remains unchanged. If rainfall is increased to equal that associated with vegetation zones of the Dakotas or Minnesota, more productive vegetation types should eventually establish themselves in Montana. Observations of changes in species composition on irrigated plots over five to six years will help us predict whether the transition would be smooth or disruptive. The following statements summarize observations made in 1977-1978.

Table 1. A summary of irrigation treatment and responses (soil water availability, total production, and reproductive production) on two types of grassland.

| | | Control | 6mm | 12mm | Fall Wet | Spring Wet | Wet |
|---|---|---|---|---|---|---|---|
| I. *Agropyron smithii* | | | | | | | |
| water added (mm) | 1977 | 0 | 25 | - | - | 275 | 480 |
| | 1978 | 0 | 17 | 55 | 164 | 59 | 321 |
| soils dry | 1977 | 15 JUN | 15 JUN | - | - | 25 AUG | never |
| | 1978 | 10 JUL | 15 JUL | 15 JUL | 15 AUG | 25 JUL | never |
| total production (%) | 1977 | 100 | 110 | - | - | 390 | 391 |
| | 1978 | 100 | 103 | 127 | 216 | 195 | 340 |
| seed production (%) | 1977 | 100 | 150 | - | - | 600 | 300 |
| | 1978 | 100 | 139 | 184 | 1618 | 982 | 2640 |
| II. *Bouteloua gracilis* | | | | | | | |
| water added (mm) | 1977 | 0 | 23 | - | - | 232 | 414 |
| | 1978 | 0 | 36 | 86 | 190 | 101 | 324 |
| soils dry | 1977 | 10 JUN | 10 JUN | - | - | 1 AUG | never |
| | 1978 | 13 JUL | 10 AUG | 21-15 AUG | 15 AUG | 15 AUG | never |
| total production (%) | 1977 | 100 | 122 | - | - | 400 | 530 |
| | 1978 | 100 | 105 | 132 | 145 | 202 | 250 |
| seed production (%) | 1977 | 100 | 200 | - | - | 800 | 800 |
| | 1978 | 100 | 238 | 271 | 180 | 280 | 369 |

1) Moisture loving grasses (*Sorghastrum nutans, Andropogon gerardii, Andropogon scoparius* and *Panicum virgatum*) planted in all treatment plots established themselves in the wet and spring wet plots at both sites, but a second summer at the *Bouteloua* site. Their success at the *Agropyron* site is apprently less, though this might be due to temporary destruction by a severe hailstorm. 2) More xeric grasses (*Bromus inermis, Stipa viridu Agropyron dasystachyum*) failed to establish in any plot. 3) Several weeds invaded our wet plots. They include *Melilotus officinale, Helianthus annus, Conyza canadensis, Sporolobus crypandrus,* and *Euphorbia spp.* Several weeds such as *Chorospora tenella* and *Lappaula echinata* seem to prefer the fall wet plots. Several weeds, including *Bromus japonicus,* and *Sisryrinchum altissimum,* seem to prefer relatively dry plots. With the exception of an outbreak of *Melilotus officinale* (sweetclover) on one of our constantly wet plots, no drastic changes in range composition were observed.

No outbreaks in pest species were observed after the first two years. Insect consumption may be even less in wet than in dry plots. Fungal-bacterial diseases, detectable by leaf spots, were not more prevalent in wet plots than in dry plots in 1977; though 1978 data are still unanalyzed, field observations don't suggest significant increases on wet plots. Ergot, a fungus causing abortion in cattle, was more prevalent in wet *Agropyron* plots than in dry plots in 1977. In the relatively wet year of 1978, Ergot was widespread on the range and seemed to differ little between plots, but due to a severe hailstorm, this statement cannot be documented with sampling data. Since populations grow logarithmically, pest outbreaks are not expected in the first year or two; our data must therefore remain inconclusive in this respect for four to six years.

## Work Projected

Irrigation and observation of our experimental plots is planned for the next four years. Obervations in 1979 will help solidify our conclusions about the responses of *Bouteloua* and *Agropyron* to supplemental water. Observations to be made between 1979-1982 will be required to draw meaningful conclusions with respect to invasion of desirable organisms or pests (weeds, insects, or diseases). In 1983 and 1984 the response of grassland communities to discontinued irrigation will be observed to determine whether they will collapse as some range managers predict.

Several accessory studies are planned: 1) Water loss rates after irrigation events will be contrasted with water loss rates after natural rainfall to evaluate the importance of the 'oasis effect' in our studies; that is, to determine how much our studies underestimate the effects of additional rainfall. 2) The hypothesis that the growing season is closed by daylength or achievement of full size (=absence of grazing) will be tested. If the first factor is controlling production, precipitation augmentation program for range forage production in Augusut will be futile. 3) The effects of single large showers on forage production will be determined. 4) Possibly, laboratory and field measurements will be made to ascertain what mechanisms control the responses of plants to large and small showers.

B. Effects of precipitation augmentation on carbon cycling and community dynamics of consumers and decomposers in Great Plains rangeland.

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## Introduction

The principal concerns of this study are related to the responses of herbivores such as the grasshoppers, aphids and cattle to increased rainfall in the rangeland ecosystem. Most measurable changes due to successful precipitation augmentation programs are likely to be transmitted through the plants (primary producers) since plant growth is largely dependent on available soil moisture (Perry, 1976 and Weaver and Collins, 1977). Some grazing animals may also be directly sensitive to precipitation effects or soil moisture changes. For instance, most herbivores, especially small and short-lived species, are food limited and slight changes in vegetation abundance can be amplified up the food chain (Wiegart and Owen, 1971 and Sinclair, 1975). Moreover, grasshopper eggs need a moist soil to develop but are killed in large numbers by pathogens when soil water is excessive (Pickford 1966).

Herbivorous arthropods (insects and related forms) were chosen for study because they can be an economic threat to agriculture in semi-arid environments (Anderson, 1970). They influence nutrient cycling and are a major food source for other animals (Rodell, 1977 and Mitchell and Pfadt, 1974). For example, many of the more common arthropods, which have been studied in detail, are greatly influenced by weather (Dempster, 1963, Gage and Mukerji, 1977, Gossard and Jones, 1977 and Symmons, 1959).

My first concern in this study then, is whether the most common chewing and sucking herbivorous insects will respond in similar proportion to rainfall increases or will they increase or decrease disproportionately. My reason for this concern is because the two groups differ in several ways:

1) plant diseases are carried more often by sucking insects;
2) sucking insects greatly increase mineral cycling rates and nutrient availability via rapid bacterial decomposition of their sugar rich feces;
3) chewing insects may reduce photosynthetic area and leaf tissue to a greater extent;
4) qualitative changes in seed numbers may be influenced by chewing insects; and
5) selective feeding by either group may enhance survival chances for some plant species relative to others.

Regulation of ecosystem production by consumers is thought to be principally affected by herbivorous insects (Mattson and Addy, 1975 and Chew, 1974).

Changes in feeding levels above the herbivorous groups are possible. In fact, one of the major reasons for precipitation augmentation research in the northern High Plains is to increase beef cattle yield for man's consumption. On a lesser scale spiders and other predators of rangeland insects may also change in abundance. If they increase in number they may help regulate insect herbivory through increased predation. Disproportionately greater increases among predators than herbivores have been noted in several studies where ecosystems were enriched with water (Kirchner, 1977 and Hurd and Wolf, 1974). Conversely, ecosystem stress through the effects of pesticides, pollutants, or severe plant loss most often leads to a decline in predators and occasionally eruptions of herbivores insects (Barrett, 1968 and Oka and Pimental, 1976).

I have hypothesized, therefore, that chewing insects, represented mostly by grasshoppers, will decline in numbers and biomass with increased rainfall while sucking insects are likely to increase in abundance, biomass and the length of time present during the growing season. Thus, if the above statement holds true, the chewing insect/sucking insect ratio will decrease. Additional changes that might be hypothesized include chewing insect turnover rate (annual production/biomass) should increase and nymph survival rates and growth rates should both decrease. If effects are severe, the ratio of egg production to surviving females may also drop.

A number of interacting factors provide a basis for the above hypotheses. First, nutritional quality may diminish with additional rainfall for those organisms chewing on plant tissue. This may occur through:

1) a substantial increase in inedible structural carbohydrates (Pickford, 1962 and Bokhari, 1978);
2) an increased production of plant chemicals to discourage feeding (Bernays et al. 1974); and
3) decreased use of highly edible amino acids (and perhaps sugars) for osmotic regulation (Smith and Northcott, 1951 and Naylor, 1972).

White (1976) identified the last factor as the driving force in locust plagues and high grasshopper concentrations. In his view, the nitrogen rich food in the drought stricken environment greatly raises nymph survival and growth rate so adults are not only more numerous, but occur in high numbers earlier in the growing season when more plants are likely to be edible. Grasshoppers cannabalize principally during times of protein stress so this may exacerbate other malnutrition related declines. The common observation of greater grasshopper numbers during drought years in the High Plains is consistent with his hypothesis.

Second, plants which experience an environment with available water transpire more which aids sucking insects in acquiring food. This means that

plant transpiration is a first requirement for maintenance, growth and reproduction of sucking insects. With available water, adequate amounts of amino acids and sugar move in the xylem and phloem tissues of plants which provides the food for sucking insects (Dixon, 1973). Some of the more noticeable leaf sucking insects, e.g., aphids and leafhoppers, may pump large volumes of plant sap to get the requisite food supply.

Third, increased predation on grasshoppers is likely with increased rainfall. Spiders are numerically the largest predator group capable of eating grasshoppers and increased rainfall should allow them to increase. Greater young spider survival will occur due to the direct effect of greater moisture. Spiders are physiologically sensitive to water; they need large amounts relative to their body size because of their protein diets which requires more water for regulating their internal osmotic environment. Additionally, for web building spiders, greater vegetation growth leads to a greater density of possible web locations and increased probability that a flying or jumping insect, such as grasshoppers, will be captured. However, many sucking insects can minimize spider predation by being relatively immobile particularly during their feeding.

Fourth, fungal diseases are known to be more effective in causing increased mortality in grasshopper species in wet years.

Fifth, increased plant stem and leaf density and height with increased rainfall present a problem for grasshoppers in addition to the greater predation risk. Such alterations make it more difficult to bask directly in the sunlight and to join in group displays necessary for proper mating behavior. Inability to bask makes them more sensitive to stalking predators and some pathogens because they will be colder longer each day and move more slowly. Sanger (1977) studied many characteristics of habitat necessities of grasshoppers and found structural features to be very important. Highest grasshopper numbers and diversity were found in the simplest grassland environments. While there are undoubtedly sucking insects whose mode of existence is favored by more open conditions, previous work has shown increases in their total density and diversity with greater structural complexity (Southwood and Van Emden, 1967 and Denno, 1977).

The above hypothesized effects and others on chewing and sucking insects are summarized in Tables 2a and 2b. The basic point of the information on the table is that the environment of rangeland insects is very complex. Single factor, cause-and-effect relationships of any ecological significance are probably the exception rather than the rule. Consideration, particularly in research design, should be made of a casual nexus incorporating positive and negative feedback influences. The multiple factor study, described below, is designed to consider concurrently several of the more apparently important variables. This should give a better window of the possible real world relationships of rangeland insects to influences of precipitation augmentation programs.

## Experimental Design

Field and enclosed experimental plots were established in a 6 acre short grass prairie site located on the Livestock and Range Experimental Station near Miles City, Montana in May of 1978.

The experimental design of the field plots has four levels of water treatment and a mowed treatment. Each treatment is replicated twice. Water levels sought are:

1) drought, in which several showers are interrupted to intensify soil moisture stress,

2) control, which receives only natural rainfall,

3) western North Dakota, and

4) central North Dakota.

In the latter two treatments, water is added by sprinkler irrigation to mimic the average soil moisture conditions of the increasingly moist Dickinson, North Dakota (available soil water until July 1) and Jamestown, North Dakota (available soil water all growing season) regions.

Mowing is scheduled for mid-July to a uniform 8-10 cm height. Mowing is being done to test the response of insects to structural simplifications and the response of plants to overstory removal. It is intended as an experimentally practicable and reproducible mimic of cattle grazing without trampling and manuring effects of cattle.

In addition to the field plots described above, other plots are enclosed with insect screens (2.4m x 2.4m x 1.2m) and have the same water treatments. These plots are replicated thrice. Known numbers of grasshoppers are added to each enclosed plot to attain data on growth rates, mortality rates and egg-laying capacities.

Parameters being measured periodically on both types of plots are described below. Detailed weather data are available from the meteorological stations at the two nearby plant ecology sites and at the Miles City Airport. During the 1978 field season variables measured on each plot included:

1) weekly; a) precipitation, (b) soil moisture at soil depths of 10, 25, and 75 cm;
2) biweekly; a) insect numbers, (b) insect types by foraging group, (c) insect biomass, (d) small mammal numbers, (e) species composition.
3) monthly; a) vegetation height, (b) vegetation cover, (c) biomass and chemical composition of five principal plant species. Specific measurements included: litter, water content, protein content, total nitrogen content, lipid content, mineral content, and non-structural carbohydrates. The five species include western wheatgrass, blue grama, needleandthread, fringed sage and threadleaf sedge.

Table 2a. Possible enhanced precipitation induced ecological changes, predicted response and relative community effect on chewing insects.

| Ecosystem Change | Insect Response | Chewing +/- |
|---|---|---|
| Increased precipitation | Higher fungal disease risk | - |
| | Lowered body temperature | - |
| | Body damage from rain | - |
| Increased soil moisture | Increased egg hatching (from low to moderate soil water) | + |
| | Increased egg morbidity (from moderate to high soil water) | - |
| | Delayed emergence from cooler soil | - |
| | Lowered body temperature from cooler soil | |
| Increased plant growth a) lower amino acid concentration | Lower survival rates | - |
| | Lower growth rates | - |
| | Delay in reproductive activity | - |
| b) increased struct. carbohydrate conc. | Less egg production | - |
| | Increased cannabalism | - |
| c) Increased leaf density | More feeding sites | + |
| | Less foliage competition | + |
| | Greater shading | - |
| | Greater predation probability | - |
| | Less behavioral contact | - |

Table 2b. Possible weather modification induced ecological changes, predicted response and relative community effect on sucking insects.

| Ecosystem Change | Insect Response | Sucking +/- |
|---|---|---|
| Increased precipitation | Higher fungal disease risk | - |
| | Lowered body temperature | - |
| | Body damage from rain | - |
| | Egg damage (eggs on plants) | - |
| | Less dessication | + |
| Increased soil moisture | (Unknown) | |
| Increased plant growth | | |
| a) longer season of plant sap movement | Higher growth rate | + |
| | Greater reproduction (may be more than one generation per season | + |
| b) more intense plant sap movement | Higher growth rate | + |
| | Greater reproduction | + |
| c) increased leaf density | More feeding sites | + |
| | More cover from predators (insects are principally immobile) | + |
| | More oviposition sites | + |
| d) increased litter | More oviposition sites | + |
| | More cover from predators | + |
| e) more plant defense compounds | Reduced feeding | - |
| Ameliorated micro-climate (principally from c) and d) above) | Lowered physiological stress | + |

While slight revisions in sampling techniques will be made in 1979, the basic data set will be retained with the possible exception of the very time consuming and highly variable plant biomass measurement. If plant biomass is not measured directly at monthly intervals, it will be assessed indirectly with a capacitance meter. Cessation of detailed biomass sampling will free research time for more precise sampling of more important variables and perhaps allow the addition of leaf area measurements. Leaf area index has been used to preduct the area of plant transpirative surfaces and can also be used to measure plant shading and leaf density pertinent to insect ecology.

During the 1978 field season insect samples were taken biweekly by suction sampling on the experimental plots at the one animal and two plant ecology sites. Insect samples were also taken biweekly on non-experimental areas around all three experimental sites by sweep netting and suction sampling. Measurements of vegetation structure were made at all three sites. These data allow comparison between years and among rangeland types.

## Results

Results from 1977 and 1978 studies will be detailed in the technical report scheduled for 1979. At present tentative statements can be made about insect numbers and biomass on the blue grama and western wheatgrass site in 1977 and 1978 and some completed analyses on the animal ecology site in 1978.

Both the blue grama and western wheatgrass sites showed significantly fewer chewing insects in the wet year of 1978 than in hot-dry year of 1977 with the most striking drop from June through July at the time of usual peak numbers and biomass. Conversely, predatory arthropod numbers were up greatly in the 1978 samples. Grasshopper nymph emergence was delayed several weeks in 1978. However, in late August 1978, the insect samples showed more grasshopper nymphs than at the same time in 1977, but they were principally forb, not grass, feeding species and were from the group that is less common and over-winters above ground. These tentative findings support the hypothesis stated above as they reflect responses to the greatly different meteorological conditions between the years. Analyses of the sucking insect data have not yet been completed.

On the experimental plots in 1978 the differences which did exist were minor due to the very wet spring which kept soil moisture levels abnormally high for nearly all of the growing season. Only minimal soil moisture differences were achieved on the experimental plots except for the central North Dakota plots which were kept at field capacity during the entire season. Most plants completed reproductive activity and became dormant before soil water was limiting on either control or drought treatments.

The following differences were noted. Plant tiller density and height were significantly positively correlated with increases in soil moisture but only on the mowed treatments. Grasshoppers seemed to show preferences for the mowed treatments but no water effect could be demonstrated from the data analyzed to date. Differences in plant biomass among the treatments could not be demonstrated although the water content (an indirect measure of plant growth capability) of most species of plants were significantly greater among the mowed "wND" and "cND" treatments. Chemical analyses of the foliage has not been initiated because of equipment difficulties in the labs at the University of Georgia. The grasshopper enclosure experiments were disrupted by a severe hail storm in mid-July. No significant differences in survival or growth rates could be established among those treatments of grasshoppers by the end of the experiment in late August.

A FORTRAN-based simulation model of a 12-15 component rangeland system is being constructed to test the hypothesis in a different way. The present stage of that operation is conceptual modeling and the gathering of equations for the major weather factors such as evapotranspiration and precipitation.

## C. The effects of increased rainfall on native forage production in eastern Montana

John Newbauer
Richard Moy

### Introduction

It is well known that changes in precipitation will alter the floristic composition of short- and mid-grass prairies in northern High Plains (Perry, 1976). Many investigators have discussed the effects of droughts upon rangeland vegetation but, as Coupland (1959) and Perry (1976) have stated, little information has been published correlating effects of many years of near normal or above normal precipitation upon this vegetation. The statistically significant increase in natural rainfall (23 percent), mostly in the months of April and June between 1963 and 1975 compared to the previous 13 years (1949-1962), provided us an excellent opportunity to predict and quantify the probable late mid-term effects of a precipitation augmentation program on native rangeland production and composition near Mildred, Montana.

### Methods and Results

Five permanent sites representing the native vegetation and three range classifications (silty, sandy and thin hilly) near Mildred, Montana, were mapped by basal area (area covered by plant bases) in 1963 and 1975. These sites were grazed lightly to moderately by cattle. To minimize the effects of different soils the basal area data on similar range sites were combined.

Total basal area at all range sites increased 61 percent between 1963 and 1976 with the silty, sandy and thin hilly range sites increasing 58, 34, and 101 percent respectively. Basal area increases at the silty and thin hilly range sites were statistically significant. However, because some of the plots at the sandy site were lost over the past 40 years, the sample size was too small for a statistical comparison. In 1963, the dominant plant was a low growing perennial (blue gramma), but by 1976 the trend appeared to be changing slightly toward more mid-grass species such as needleandthread and prairie junegrass. Needleandthread, western wheatgrass, and prairie junegrass became established or increased on all sites. Threadleaf sedge increased on the silty and thin hilly sites, but decreased slightly on the sandy range sites. Since the above five species accounted for approximately 85 percent of the total basal area, the data for these grasses or grasslike species were analyzed further. The calculated forage yield of these species increased 192 (110 percent), 182 (62 percent) and 130 kg/ha (109 percent) on the silty, sandy and thin hilly range sites respectively, between 1962 and 1976. Even though forage production increased the least on the sandy range site, this range site was more productive than the other two sites (480 kg/ha versus 249 kg/ha for the thin hilly and 367 kg/ha for the silty range sites). The increase in forage

yield of these species increased the calculated grazing capacity for cattle from 3.1 to 1.5 hectares per cow month on the silty range sites, from 1.8 to 1.1 on the sandy range sites and from 4.6 to 2.2 on the thin hilly range sites.

## Discussion

These results indicate that additional spring - early summer precipitation on moderately grazed rangeland in eastern Montana has benefits for the livestock producer. Our data suggests that the number of cattle that may be properly grazed might almost double with a 23 percent increase in precipitation. Coupland (1959) reported similar findings in southern Alberta and Saskatchewan. Whether an increase of this magnitude is consistently obtainable with advertent cloud seeding remains to be seen.

A portion of this study was presented at the First International Rangeland Congress held in Denver, Colorado, in August 1978, and the remaining information was recently submitted to the Journal of Range Management for publication.

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## CHAPTER IV

## GENERAL ACTIVITIES

A. Information Programs - Larry Holman and Rich Moy

1) Public Meetings

Two public meegings were held prior to the 1977 field season in Terry and Miles City, Montana, to inform local residents of the goals and methodologies of HIPLEX research and why HIPLEX may be important to them. Thirty-three people attended the Terry meeting and twenty-eight the Miles City meeting. The active discussion and question-answer session after the HIPLEX presentations suggested a strong interest in HIPLEX activities. All members of the citizens advisory committee were invited and five attended. (Refer to the 1976 Annual Report for a discussion of the Advisory Committee.)

The basic reason for having a citizen advisory committee is to have them act as liaison between HIPLEX researchers and the citizens of the study area; that is, to provide feedback on the thoughts and feelings of both sides regarding HIPLEX research. To date, little feedback has been received from the committee. Steps are presently being taken to improve this situation.

2) Presentation by HIPLEX biologists and meteorologists

Nine presentations were given by state meteorologists and biologists on HIPLEX research to science classes at the junior and senior high schools in Miles City prior to the 1978 field season. Six subsequent field trips were made through the facilities at site headquarters and to the biological experimental sites at Ft. Keogh. The students appeared quite interested in HIPLEX as indicated by the questions generated after the presentations and from the polls taken by the classroom instructors. The findings of the poll showed the following:

(a) 79 percent of the students felt that HIPLEX research was essential or useful to enhance the well being of Montana.

(b) Only 16 percent of the students thought their parents were very interested and aware of HIPLEX; 37 percent of the students thought their parents could become very interested, but that they were not familiar with HIPLEX activities.

(c) Approximately 87 percent of the students thought the presentations were good or very good.

These findings suggest that further informative programs are needed to acquaint the citizens of Miles City with HIPLEX research. Further classroom presentation and information meetings are planned.

Table 3 is a listing of all talks presented by HIPLEX biologists and meteorologists.

3) "Weather Modification in Montana" Bulletin

A bulletin, entitled "Weather Modification in Montana," is published quarterly by Bob Yaw of the Department of Earth Sciences, Montana State University. The purpose of the news bulletin is to inform interested

| DATE | LECTURER | ORGANIZATION | LOCATION | TITLE | NUMBER ATTENDING |
|---|---|---|---|---|---|
| 4-14-78 | Jim McInerney | Custer County High School | Miles City | HIPLEX (general) | |
| 5- 1-78 | Biologist and Staff | Kircher 7 & 8 Grades | Miles City (HIPLEX) | HIPLEX Tour | 20 |
| 5- 5-78 | Biologist and Staff | Cohagen Grade School | Miles City (HIPLEX) | HIPLEX Tour | 28 |
| 5-11-78 | HIPLEX Staff | Public | Miles City (HIPLEX) | HIPLEX Tour | -- |
| 5-12-78 | HIPLEX Staff | Public | Miles City (HIPLEX) | HIPLEX Tour | |
| 5-26-78 | Tad Weaver | Physics Department | Montana State Univ. | Possible effects of enhanced precipitation on Mt. rangeland | |
| 7-21-78 | John Newbauer and Staff | Youth Conservation Corps | Miles City (HIPLEX) | HIPLEX Tour | 31 |
| 8- 8-78 | Jim McInerney | Public | Miles City (HIPLEX) | HIPLEX Tour | |
| 9- 5-78 | Bob Yaw | Rotary | Townsend | HIPLEX (general) | 26 |
| 9-25-78 | Bob Yaw | City-County Planning Board | Baker | HIPLEX (general) | 19 |
| 10-30-78 | Bob Yaw | City-County Planning Board | Baker | HIPLEX (general) | 18 |
| 11-27-78 | Bob Yaw | City-County Planning Board | Baker | HIPLEX (general) | 23 |
| 11-29-78 | HIPLEX | Public | Miles City (HIPLEX) | HIPLEX (general) | |
| 12- 8-78 | Bob Yaw | Rural Area Development Committee of Montana | Bozeman | HIPLEX (general) | 27 |

TABLE 3. TALKS PRESENTED BY HIPLEX PERSONNEL IN 1977 AND 1978

| DATE | LECTURER | ORGANIZATION | LOCATION | TITLE | NUMBER ATTENDING |
|---|---|---|---|---|---|
| 1-11-77 | Larry Holman | KATL Radio | Miles City | Season Operation | -- |
| 1-18-77 | Marty Lyman & Ann Losinski | | Miles City (HIPLEX) | HIPLEX Tour | -- |
| 1-20-77 | Bob Yaw | Mt. Water Development Association | Helena | HIPLEX (general) | 25 |
| 2-17-77 | Bob Yaw | Rotary | Kalispell | HIPLEX (general) | 95 |
| 2-22-77 | Bob Yaw | Kiwanis | Billings | HIPLEX (general) | 80 |
| 2-23-77 | Bob Yaw | Agricultural Group | Broadview | HIPLEX (general) | 22 |
| 2-24-77 | Joey Boatman | Lions Club | Miles City | HIPLEX (general) | -- |
| 3- 3-77 | Bob Yaw | Mt. Wilderness Association | Great Falls | HIPLEX (general) | 18 |
| 3- 4-77 | Tad Weaver | Biology Department | Brigham Young Univ. | Ecological effects of winter and summer weather modification | -- |
| 3- 8-77 | Bob Yaw | USDA Committee for Rural Development | Bozeman | HIPLEX (general) | 7 |
| 3-14-77 | Bob Yaw | Kiwanis | Great Falls | HIPLEX (general) | 85 |
| 3-22-77 | Bob Yaw | Commercial Club | Stanford | HIPLEX (general) | 32 |
| 3-23-77 | Bob Yaw | Agriculture and Livestock Committee Chamber of Commerce | Great Falls | HIPLEX (general) | 42 |
| 3-24-77 | Larry Holman and Bob Yaw | Public Meeting | Terry | HIPLEX (general) | 14 |
| 3-24-77 | Larry Holman and Bob Yaw | Public Meeting | Miles City | HIPLEX (general) | 28 |
| 4- 6-77 | Bob Yaw | Rotary | Helena | HIPLEX (general) | 72 |
| 4-13-77 | Staff | Public | Miles City (HIPLEX) | HIPLEX Tour | -- |
| 5-16-77 | Bob Yaw | Rotary | Billings | HIPLEX (general) | 184 |
| 5-24-77 | Bob Yaw | Rotary | Great Falls | HIPLEX (general) | 103 |
| 6-26-77 | Staff | Public | Miles City (HIPLEX) | HIPLEX Tour | -- |
| 6-29-77 | John Newbauer & Larry Holman | Soil Conservation Range Tour | Terry Area | HIPLEX Range Tour | 44 |
| 8-28-77 | Tad Weaver | Department of Commerce NOAA Advisory Committee | Miles City | Ecological effects of summer weather modification | -- |
| 11-14-77 | John Newbauer | Kiwanis | Miles City | Ecological research at HIPLEX | 35 |
| 1-21-78 | Bob Yaw | Rotary | Bozeman | HIPLEX (general) | 90 |
| 2-24-78 | Jeff Birkby | Plant and Soil Science Department | Montana State Univ. | Ecological effects of enhanced precipitation on Mt. rangeland | -- |
| 2-26-78 | Tad Weaver | Lions Club | Miles City | Possible effects of enhanced precipitation on Mt. rangeland | 45 |
| 3- 6-78 | Tad Weaver | Biology Department | Montana State Univ. | Possible effects of enhanced precipitation on Mt. rangeland | |
| 3- 7-78 | Tom Engel | Custer County High School | Miles City | HIPLEX (general) | |
| 3-11-78 | Bob Yaw | Kiwanis | Missoula | HIPLEX (general) | 85 |
| 4- 3-78 | John Newbauer | Custer County High School | Miles City | Ecological research at HIPLEX | 11 |
| 4-12-78 | Larry Holman | Sacred Heart High School | Miles City | HIPLEX (general) | |
| 4-12-78 | Larry Holman | Custer County High School | Miles City | HIPLEX (general) | |
| 4-12-78 | Jim McInerney | Custer County High School | Miles City | HIPLEX (general) | |
| 4-13-78 | John Newbauer | Sacred Heart High School | Miles City | Ecological research at HIPLEX | 10 |
| 4-13-78 | Tom Engel | Sacred Heart High School | Miles City | HIPLEX (general) | |
| 4-14-78 | Tad Weaver | Plant and Soil Science Department | Mt. State University | Effects of light rainshowers on | |

individuals about HIPLEX research activities, cloud seeding activities in other states, and about national weather modification activities. The bulletin is planned to be published approximately quarterly throughout the duration of the HIPLEX program.

B. Support Services - Larry Holman

1) Clerical

Clerical responsibilities were approximately the same as described in the 1976 annual report except for the following changes:

(a) Assisted with field operations such as preparing forecast materials and launching rawinsondes.

(b) Assisted with data collection at the native rangeland experimental sites.

(c) Drafted figures and maps.

The percentage of time spent by the clerical staff on various projects are estimated in Table 4.

Table 4. Percentage of Time Present at Various Data Clerk Activities

| Activities | Percentage of Time |
|---|---|
| Agro-ecological field work | 4% |
| Agro-ecological data handling | 2% |
| Precipitation data handling | 25% |
| Drafting figures and charts | 6% |
| Meteorological field data collection | 7% |
| Typing | 10% |
| Scheduling, accounting and filing | 10% |
| Receptionist | 6% |
| Radar boxing | 25% |
| Other miscellaneous | 5% |
| | 100% |

One full-time secretary and four full-time data clerks were enough to carry out all normal clerical activities. However, for the boxing of the radar echoes, six additional data clerks were temporarily needed.

2) Facility Maintenance and Repair

Considerable effort was expended in maintaining and repairing headquarter facilities, and storage areas. Extensive cleanup, repair, and painting was required to return the complex to a usable condition after the severe hailstorm of July 18, 1978. Eight windows were replaced and ten old windows were removed and covered with plywood. The front of the trailer complex was resided with masonite and painted.

3) Equipment Service and Repair

Our radar technician serviced, repaired and maintained such equipment as the SWR-75 radar, the RD-65 rawinsonde instruments, Cyber 74-28 computer terminals, 2-way radios and some office equipment until he terminated his contract in March, 1978. The position was not refilled by the state.

C. Computer software design - Tom Engel and Jim McInerney

Much of the work summarized in the Data Analysis and Meteorological Planning section of this report required development of computer software to make the work more efficient. This section is designed to document the existence of this software so that such capabilities need not be reproduced by others.

Software on the Bureau of Reclamation's Cyber computer system:

1) Several software packages were designed to process, analyze and edit the 1976 Montana precipitation data base. These included routines to (1) find missing data in the data base, (2) find data duplication, (3) generate 1976 format card images from digitized data, (4) merge corrections files with the existing data base, (5) generate a listing of precipitation periods, and (6) plot scaled maps of precipitation amounts.

2) Several packages were designed to list, analyze and plot aircraft data. These included routines to (1) retrieve University of Wyoming Queen Air data, determine times of cloud penetration and list, average and plot selected cloud physical parameters, (2) produce statistical summaries and calculate distributions of desired measured parameters for passes through clouds, and (3) plot both VOR/DME and FAA flight track data.

3) Several analysis packages were designed for precipitation data. Included in these are routines which (1) determine total measured precipitation volume for each "storm" event, (2) determine hourly precipitation averages over the network, (3) calculate statistical quantities for precipitation events, (4) determine maximum rain rates, and (5) list precipitation for matched pairs of gages.

4) A generalized mapping package for producing scaled maps and plots was designed for a line printer so that plots can be produced on any desired scale for intercomparison purposes.

Software on the Tektronix 4051 minicomputer/4956 digitizing system:

1) A routine to produce data on convective complex radar coordinate definitions which are compatible with existing software on the Cyber computer system for reduction, analysis, and display of radar data. This "boxing" routine was written in cooperation with Doug Hale of the Bureau of Reclamation in Denver.

2) A routine to transfer the radar boxing data from the Tektronix 4051 to the Cyber computer system in Denver and create appropriate data files.

3) A generalized plotting package to generate high quality plots from data entered from either the keyboard or magnetic tape. This routine can be used by someone unfamiliar with programming on the 4051.

4) A routine to reduce pyrheliograph charts was developed for use by the Range Biologists.

5) A linear regression routine was developed to calculate and plot linear regressions.

D. Academic Involvement of Montana State University in HIPLEX - Jim Heimbach

The High Plains Experiment offered a unique opportunity for meteorology students at Montana State University to participate in an active field project employing state-of-the-art equipment, and to examine some of the latest concepts in cloud seeding research. Although every attempt is made within a cúrriculum to extend theory from the abstract to the practical world, it is very difficult to do an adequate job because of budget and time constraints. The HIPLEX Project, therefore, provides eligible students such as opportunity. Students were considered eligible if they had completed their sophomore year and the Meteorological Instruments course. This lessened the amount of on-the-job training necessary for their respective responsibilities. A majority of the participants were allowed to enroll in six or twelve hours of Internship and in so doing were able to gain credit for their HIPLEX experience.

Potential employers were presented with a list of names and qualifications. In several cases personal opinions were solicited regarding a student's interests and strengths. Employers were not pressured to take one applicant over the other; all hiring was done on a first-come basis.

Table 5 lists the students and their involvement. The Montana Department of Natural Resources and Conservation was the largest employer. One of their particpants was assigned to J. Heimbach at MSU to assist with ongoing HIPLEX research. The other two helped maintain the 1977 gage network. Other contractors were the University of North Dakota and Western Scientific Services, Inc. The principal investigator of the latter group returned in 1978 with Western Weather Consultants, Inc. Only one student position was available in 1978 because there was no rain gage network and the University of North Dakota did not participate in Montana HIPLEX field activities. With Phase II ushering in a more active field season, MSU is looking forward to having their students particpate in further HIPLEX research.

Table 5. Montana State University Student Involvement in HIPLEX

1977-1978

| Name | Season | Contractor | Duties |
|---|---|---|---|
| Kraig Gilkey | 1977 | MTDNRC | Research at MSU on rain cell and radar data reduction |
| Brad Miller | 1977 | UND | Radar and radiosonde operator |
| Dennis Hull | 1977 | MTDNRC | Rain gage network maintenance |
| Jim McInerney | 1977-1978 | MTDNRC | Rain gage network maintenance and data reduction (remained in full employment after end of 1977 field season) |
| Bruce Boe | 1977 | WSSI | Radar operator, rawinsonde operator |
| | 1978 | WSSI | Radar operator, rawinsonde operator |
| William Campell | 1977 | UND | Radar and radiosonde operator |
| Dan Risch | 1977 | WSSI | Forecaster's assistant |
| | 1978 | WWCI | Forecaster's assistant |

MTDNRC: Montana Department of Natural Resources and Conservation
WSSI : Western Scientific Services, Incorporated
UND : University of North Dakota, Department of Aviation, Grand Forks
WWCI : Western Weather Consultants, Incorporated